CORVINUS UNIVERSITY BUDAPEST

QUALITY OF WATER USED FOR IRRIGATION IN FORCED CULTURES OF VEGETABLES IN HUNGARY

Theses of the Ph. D. dissertation

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1. ANTECEDENTS AND OBJECTIVES SET

Vegetable forcing enjoys of traditions over several generations in the Southern Great Plain region of Hungary. Since the political changes of 1989, forced culture of vegetables received more attention, and competition of growers became more severe. Also criteria of food safety and ecological compatibility received more attention. Monoculture caused a gradual decline of soil conditions; nematodes and salt accumulation stimulated the growers to choose alternative practices as soil less cultures, which proved their value in Western Europe.

Exact statistics are lacking, but estimates deal with approximately 300-400 hectares of vegetable forcing on rock wool, whereas other substrates of soil less culture may multiply this number. The economical weight of the branch of vegetable forcing is 300-600 times higher than the production of cereals.

Real perspectives are attributed to the forced production of pepper, tomato and cucumber.

In the soil less system of forcing, the supporting substances have a low capacity of nutrient-retention, therefore, the provision of nutrient solutions ought to be continuous, consequently, much water is required. In production, the volume of the solution applied depends on water quality, i.e. the lower quality of water, the more of it is required for a unit of crop. Excessive volumes of water mean increasing volumes of overflow, which cause an increasing environmental burden in open systems of production. Environmentally safe, closed production systems cannot be work without water of excellent quality because the overflow is reutilised.

In soil less cultures, water quality is decisive in determining the chemical conditions of the rooting zone. The chemical conditions of water are managed more or less uniformly in soil less cultures, because the interaction is minimal between the substrate and the roots. Therefore, success of soil less cultures depends largely on the quality of local water resources.

In soil less forcing, the intensity of production as well as the environmental risk is high. On the contrary, the soil stores the majority of nutrients left over by the plants, whereas a minor fraction get eroded. In open systems of soil less cultures, the nutrients being already mobilised are washed out easily with the overflow; therefore, the amount of fertilisers administered is substantially higher than in traditional field cultures.

An abundant bulk of international literature deals with the technological elements of water (soil less) culture; however, questions related to water quality were treated scarcely. Recently, also ecological concern became an important moment in dealing with the fate of nutrients being utilised. Minimising of the loss of nutrients has been considered in closed systems of production only.

On the other hand, Hungarian publications are rather few, and new technologies are often adapted and introduced without previous experimental approach. A thorough survey of water resources utilised for soil less cultures is still wanted.

Data related to losses of nutrient elements in open soil less production systems and their consequences are plainly lacking.

Therefore, studies have been initiated to reveal the conditions of water resources from the point of view of their suitability for plant nutrition and irrigation during the last ten years. Results obtained may help to utilise the water reserves of the Southern Great Plain region for the purpose of "ecologically conscientious" soil less plant production.

The bulk of problems have been approached from an environmentally conscious point of view by terms of my erudition acquired in chemistry. Therefore, I hope that it will contribute to the theoretical as well as practical development of vegetable production in my country.

Objectives set for the research work:

- to follow up the path of water from the source through the preparation and distribution of nutrient solutions, interaction with the roots of plants, the tendency of changes of its chemistry observed in the overflow;
- the water sources of the Southern Great Plain region are characterised regarding their chemical properties, the anthropogenic causes of pollution and the stability of composition;
- analysis of individual water resources as for their suitability to prepare nutrient solutions and possibilities of improving the water quality;
- research aimed to reveal the micro element content of layer waters in the Southern Great Plain region;
- to assess optimal nutritive solutions for the three most important vegetables of forced cultivation (pepper, tomato, cucumber) based on selected layer water resources (as models of water chemistry of the Southern Great Plain region);
- to analyse the nutrient-plant interaction in experimental production;
- to assess the utilisation of nutritive elements in experiments with the respective vegetable species;
- to trace the role of individual properties of water chemistry from the point of view of utilisation of nutrients in experimental production.

2. MATERIALS AND METHOD

The scientific research endeavoured the investigation of water resources used for irrigation in the Southern Great Plain region as well as the performance of experimental production of forced vegetables.

2.1. Chemical analysis of water resources in the Southern Great Plain region

Mapping of water chemistry of the region

Samples are taken from three counties (Békés, Csongrád, Bács-Kiskun) as shown in *Table 1*. The same sources have been sampled repeatedly in order to follow up the temporary changes too not only the spatial ones. The collection and processing of water samples ensued between 2000 and 2004.

- the chemical parameters of suitability for soil less plant cultivation:

  pH, EC, NO_3*-N, P, K, Ca, Mg, Na, Cl,* HCO_3

- micro-elements examined for the preparation of layer waters of the Southern Great Plain region:

  Fe, Cu, Zn, Mn, B, SO_4*-S*

2.2. Experimental production

Ecological assessment of soil less vegetable forcing

The ecological evaluation of soil less production was based upon results of purposeful experiments. Three main vegetable species have been involved in the forcing cultures (pepper, tomato, cucumber), 3 experiments were assigned to each species, so altogether 9 independent experiments were performed between March 2004 and November 2004. Roman numerals, I-IX, were assigned to the individual experiments:

Pepper (Capsicum annuum L.*)* I., II. and III.,

Tomato (Lycopersicon esculentum MILL.*)* IV., V. and VI.,

Cucumber (Cucumis sativus L.*)* VII., VIII. and IX.

All soil less culture were grown on rockwool, A-B and acid containers served for the feeding system, which administered the nutritive solution according to the procedure of trickling irrigation. It worked as an open system as the overflow left the installation.

The main data of the cultures are presented in *Table 1*.

- Measurements performed in the farms:
  - the amount of macro- and meso-elements in the fertilisers administered,
  - the amount of acids applied,
  - the total yield of any quality,

- the nutrient solutions of all plots, i.e. the medium itself as well as the overflow were sampled once in every month at the same time (hour),

➢ The solutions sampled were checked chemically as for their content:

pH, EC (electric conductivity), NO_3*-N, P, K, Ca, Mg, Na*.

Table 1

The main data of the vegetable forcing experiments in farms of the Southern Great Plain region, 2004

The identity of the experiment	The surface of the plantation (m^2)	Planting density (plant/ m^2)	Variety	Planting date	Steering of watering*	Mean rate of the overflow (%)**
Pepper						
I.	4000	4.10	'Hó F_1'	2003.12.01.	K	35-39
II.	4000	3.70	'Hó F_1'	2004.02.20.	K	28-32
III.	1220	6.39	'Keceli csüngő'	2003.12.30.	K	26-30
Tomato						
IV.	5000	2.50	'Pedrico' and 'Durinta'	2004. 01.04.	I	30-34
V.	11500	2.52	'Durinta'	2003.11.03.	K	25-29
VI.	9600	2.47	'Profilo'	2004.04.23.	I	20-26
Cucumber						
VII.	828	1.48	'Suprami'	2004.02.20.	K	18-22
VIII.	8000	1.50	'Pedroso F_1'	2004.01.15.	I	34-38
IX.	2800	1.54	'Pedroso F_1'	2004.01.20.	I	31-35

*K: climate steering of irrigation; I: time-switch steering of irrigation

**Average industrial conditions, according to the records of growers

Samples of water and nutrient solutions collected by producers were analysed in the Laboratory of Chemistry and Soil Department of Tessedik S. College. In the analysis of samples, classical and instrumental procedures have been applied.

3. RESULTS

3.1. Results of water analyses

Water resources to be utilised are first scrutinised for their origin as a preliminary information related to utility.

3.1.1. The suitability for water culture

According to the analyses of **surface water resources,** their composition is extremely variable. The suitability of surface water resources depends largely from their relation with the respective river waters. The more intense the connection with the rivers the more favourable and more stable their utility for vegetable culture. In slowly moving waters, high salt concentration used to build up because of the accumulation of overflow, sewage and other pollution, which used to be rather variable. Therefore, utilisation of those waters is not recommended for preparing nutritive solutions.

All relevant chemical properties of **ground waters** varied on a broad scale. Electric conductivity (EC) values are found between 0.79 and 4.2 mS/cm, which mean approximately 500-3000 mg/l salt content. The groundwater of the settlements was influenced essentially by the excessive use of chemical fertilisers as well as by the respective communal sewage system. For water cultures, the presence of the following ions is really decisive: Na, Cl, and hydrocarbonates. The utility of groundwater is often impaired by more than one prohibitive value above the limits.

For the origin of water samples, it is of special interest that from some settlements several samples were taken at different sites at the same time (e.g. Nagyszénás), or at different dates at the same site (e.g. Orosháza). Both cases indicate that the parameters are continuously subject to spatial and temporal variation, therefore, regular checks are necessary.

The **layer water** samples of model settlements displayed a more uniform picture of chemical properties. Electric conductivity varied: EC=0.34-0.8 mS/cm. As the most decisive anion, hydrocarbonate has been recognised. Cations are more variable. With declining calcium content the sodium content increases. Higher sodium concentration is associated with lower magnesium content most likely as a consequence of precipitation. The chemical character of layer waters is attributed to the influence of regional subsurface streams, which is convincingly expressed by the gradual softening of water streams.

As for the content of nutritive elements, nitrates are found in traces, phosphorus and potassium are scarce as expected (P: 0-2.4 mg/l; K: 0.3-6.0 mg/l).

In hard waters, the limiting factor is the hydrocarbonate content, in soft waters; the sodium content limited their use for hydroculture. Essentially, layer waters are characterised by predictable parameters on the long run.

3.1.2. Preparation of water for nutritive irrigation

Content of micro-elements

Results concerning micro-elements in the layer waters of the region are variable but do not exhibit any tendency.

Among them, iron and manganese are of outstanding importance. Their absolute concentration endangers the function of dripping system of irrigation. More than 70% of water samples predict the danger of plugging in the distribution of the nutritive solution. First of all iron, less probably manganese is to be blamed.

Improvement of water quality by desalting

Waters to be improved are layer waters as a rule, rarely ground waters. Salt content used to be less than 1 mS/cm, whereas in ground waters between 1-2 mS/cm. The main reason of desalting was in all cases the excessive concentration of sodium in the irrigation water. Results were convincing as the water output contained very low concentration of salt ($EC<0.1$ mS/cm). The actual quality fulfils the requirements set for the growing system using nutritive solutions.

Desalting is an effective procedure, although its application causes further environmental concern.

Preparation of nutritive solution with layer water

The ill-proportioned cation composition, salt- and sodium content of waters aggravate the exact preparation of nutritive solutions. Excellent, i.e. low, Na-content and EC (pepper: 3.06-3.25 mS/cm; tomato: 3.82-3.98 mS/cm; cucumber; 3.02-3.20 mS/cm) was found for immediate use at some settlements (Csólyospálos, Jászszentlászló, Kiskunfélegyháza, Zákányszék). The highest salt content was found, mainly due to high sodium content, at Méhkerék, Csanytelek and Szentes.

The high hydrocarbonate content alone does not hamper the use of water, although the obligate increment of salt concentration impairs the cultivation of salt intolerant plants.

3.2. Result of experimental production

3.2.1. The result of measurements performed in the solutions sampled during the experimental vegetable forcing

As a result of interaction between the plants and the nutrient solution, the composition of the primary solution changed. As far as regularities in changes of the most important parameters have been revealed, a reutilisation of the overflow (leaving the system) could be elaborated. The repeated utilisation will also diminish the ecological burden of the soil less production.

The mean trends of changes in pH and EC as well as in the concentration of different ions measured during the growing period and related to the primary solution are presented in *Table 2*.

Table 2

The mean trends of changes measured in the overflow of the primary solution are shown in all the 9 experiments on rockwool (2004) (↥: rise; ↓: decline)

Property	Site of sampling	Pepper	Tomato	Cucumber
pH	Medium	↥	↥	↥
	Overflow	↥	↥	↥
EC	Medium	↥	↥	↥
	Overflow	↥	↥	↥
N	Medium	↥	↥	↓
	Overflow	↥	↥	↓
P	Medium	↓	↓	↓
	Overflow	↓	↓	↓
K	Medium	↓	↓	↓
	Overflow s	↓	↓	↓
Ca	Medium	↥	↥	↥
	Overflow	↥	↥	↥
Mg	Medium	↥	↥	↥
	Overflow	↥	↥	↥
Na	Medium	↥	↥	↥
	Overflow	↥	↥	↥

We stated that concentrations of Phosphorus and Potassium declined in all species and in both sampling sites, whereas the concentration of the rest of cations (Calcium, Magnesium and Natrium) increased in both, in the medium as well as in the overflow (because of the variable values of EC or electric conductivity of the solutions were standardised to EC=3 mS/cm). The changes in nitrogen content did not show any trend.

The rising and declining concentration of cations changed the relative ratio of ions in both solutions, in the medium as well as in the overflow. The concentration of the hydroxide ions also increased by some less known reasons, i.e. the pH values rose.

3.2.2. The ecological evaluation of the overflow

As the ratio of nutrients depleted as well as left in the overflow cannot be determined directly in the experimental production, the volume of the overflow could not be plotted against the nutrients taken up by the plants.

The total input of nutrients was estimated on the basis of the concentration of the nutrient solution and the ratio of the overflow (*Table 1)*, which indicate the volume of nutrient, which left the system. By comparing the total input of nutrients and the volume lost by the overflow, the ratio of utilisation was computed for each element:

$$Utilisation\ of\ nutrients\ \% = \frac{Total\ input\ of\ nutrients - Nutrients,\ which\ left\ the\ system}{Total\ input\ of\ nutrients} \cdot 100$$

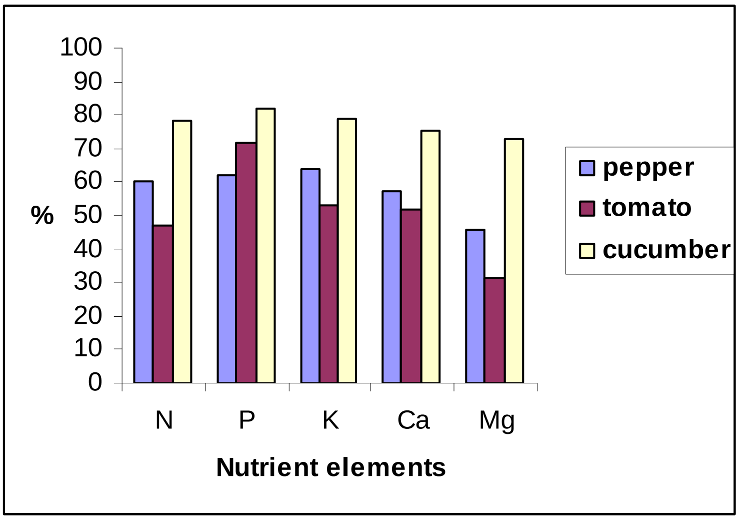

Figure 1 Utilisation of the nutrients by the three vegetable species (2004)

For the analysis of data raised in the 9 experiments, the ratios of utilisation have been applied. Computations were performed for each plant species and each farm, then also for the average of plant species over the three experiments (*Figure 1*).

In the open systems of experimental soil less cultures, the mean utilisation of main nutrient elements varied between 30 and 80 %. The utilisation changed according to the vegetable species, moreover, it is also subject to the conditions of the particular farm. Most active components are the mode of irrigation, which determines the rate of overflow and its salt concentration.

The ratio of utilisation of all nutritive elements is related to the changing concentration of overflow. Best utilisation of nutrients is displayed by those elements, which are less represented in the overflow (phosphorus and potassium). Poor utilisation is found in cations, which were present in the medium as well as in the overflow at higher concentrations (calcium and magnesium).

Climatic steering improved the uptake of nutrients substantially although it was not the sole condition of their higher rate of utilisation.

3.2.3. Utilisation of nutrients depending on the quality of water used for preparing the solution

The rate of utilisation of nutrients has been traced in relation to the composition of the water used for preparing the nutritive solutions. Critical parameters, as values of salt, mainly sodium concentration, are emphasised, which still allow a reasonable utilisation of the nutrients: N, P, and K.

The correlations revealed that the utilisation of nutrients depends on the sodium content of water, but it is not main reason if compared with other components of growing conditions. In spite of that, we may define some limiting values of salt concentration, which do not impair considerably the utilisation of nutrients: calcium 80 ppm, magnesium 25 ppm, sodium 30 ppm are the highest values tolerable. It means 7.5 mekv/l of all cations, which is correspondent to an EC of 0.7 mS/cm.

Those limits are already too high for cucumber. The best relations are found with desalted water in the farm number VII, consequently, the lowest salt content produces the best utilisation of nutrients.

3.3. New scientific results

- In the Southern Great Plain region, the suitability of water resources for the use in solutions of soil less cultures is determined by the following circumstances:
  - ✓ The existing rivers should feed surface waters. The more intense the exchange of water, the better its suitability for the purpose of nutritive solution.
  - ✓ Ground waters are threatened by anthropogenous pollution. Altogether some 4% of them proved to be “acceptable”, whereas about 1/3 of the resources were “less acceptable”, nearly 2/3 of them displayed at least one parameter beyond the limits set for hydroculture.
  - ✓ Layer waters are subject to the hydrogeological relations. Their composition is relatively stable, and depending on chemical criteria, sodium as well as hydrocarbonates may cause concern. Either infiltration from sandy ridges or rising streams from deeper strata of the Great Plain may cause either high sodium or hydrocarbonate content, which are distinguished easily.
- The local layer waters supply the main vegetables being grown in soil less forcing structures of the Southern Great Plain region sufficiently. In spite of the relatively high hydrocarbonate concentration, the suitable nutrive solutions have been still feasible.

As the salt concentration increased, more salt tolerant varieties are to be preferred. A real obstacle of using layer waters is its sodium content.

- Further concern of using layer waters means the manganese and iron content. About ¾ of the samples analysed indicate a medium risk of jamming in the distributing tubes.

  On the long run, the reduced possibility of using layer waters could be compensated by using ground waters, however, they have to be desalted.

- The composition of the nutritive solution changes mainly in the medium by the interaction with the plant, and is expressed in the overflow of the solution. According to the experiments, the calcium, magnesium and sodium content increases in the overflow, which increases the EC-value of the latter. Meanwhile phosphorus and potassium concentration diminishes as related to the original solution, and the pH value increases with the diminishing phosphorus values. For nitrogen, no unequivocal tendency could be detected.
- The utilisation of nutrients depends on the vegetable species, let alone other circumstances of production. The average rate of utilisation in macro- and meso-elements varied between 30 and 80%, the lowest rate was found in magnesium (23-75%), the highest in phosphorus (54-91%) and in potassium (51-88%). Irrigation influences the volume and the salt content of overflow; consequently, it determines the rate of utilisation of nutritive elements. The rate of utilisation of nutritive elements depends also from the changing concentration of the overflow: those elements, which are represented at higher concentration in the overflow, are utilised at lower rates. The irrigation regulated according to the intensity of radiation, in other words, climate-regulated water administration is beneficial to the utilisation of nutrients but it is not the unique condition of a good utilisation.
- The technological elements of production are more decisive from the point of view of nutrient utilisation than the chemical properties of the water used. The chemistry of water recommended for nutritive solution in an open production system is determined by the following criteria: sodium content should be lower than 1.5 mmol/l and its SAR value lower than 1. Those limits are more severe than indicated in the literature referring to irrigation water "used without limitation". The conditions outlined are valid for the layer waters of the infiltrated areas of the Great Plain only.

  The application of water cleaning devices improves the utilisation of nutrients in open production systems, subsequently, secures also the water-chemical conditions of closed production systems.

4. CONCLUSIONS, SUGGESTIONS

For soil less vegetable production of the Southern Great Plain region in Hungary, there is enough water available, however, the origin and chemical composition of it are decisive from the point of view of practicability.

4.1. Irrigation waters

Availability of *surface waters* is limited by distance, winter frost and summer drought. Chemical composition of water reserves of slow circulation is unstable because of being polluted frequently by nutrients as well as by sewage; therefore, they are not reliable sources of irrigation.

The *ground water* is everywhere accessible, although its sodium and chloride content is almost always significant, moreover, human pollution may occur (e.g. nitrates and phosphates). A further unfavourable moment is the seasonal variation observed within the area of the same community.

The abundant supply of *layer waters* in the Quaternary strata is located in more than half of the cases within the upper 50 m region. As by the expected changes of the climate, a strategic increment of the importance of subsurface waters is anticipated. It is of a primary interest to preserve their quantity as well as quality. At the moment, there are many illegal wells beside thousands of licensed ones, on the long run, environmental priorities will reduce their use significantly. The emphasised protection of layer waters is beyond question professionally because pollution of the surface did not impair their integrity yet.

At present, legal wells are still used for irrigation in forcing of vegetables. Their composition is relatively stable, and the prognoses are reliable for the same settlement. The suitability of the well depends essentially on the regional streaming system of the Great Plain, where either infiltration or uprising is dominant at the particular well. Salt content of the majority of water resources bearing hydrocarbonates is low, however, streaming of the subsurface waters tend to increase sodium content and to diminish calcium and magnesium, whereas the pH increases (mainly by ion-exchange).

4.2. Preparation of nutritive solutions

At composing the solution, excessive i.e. higher than optimal hydrocarbonate concentration could be improved successfully with inorganic acids, although salinity was raised consequently. The main vegetable species involved have a mediocre salt tolerance; all the same, high EC may cause salt accumulation of the medium, which reduces yield. By this reason, a careful choice of variety, or even a genetic selection for higher salt tolerance would be justified.

Water quality is decisive not only because of the interaction with the plants but also from the point of view of the distribution of water. Some microelements, mainly iron and secondarily manganese may cause problems; therefore, irrigation water ought to be prepared carefully. A technical equipment using aeration for the elimination of iron should complete production technology.

4.3. Caring for the overflow in open systems of production

Vegetable growers of soil less hydroculture are obliged to keep care for the overflow. An essential aspect is the secondary utilisation of the solution leaving the system also from the point view of diminishing the environmental burden, which means a switch to a closed production system.

Results of the analysis of solutions leaving the open production system prove that radiation and irrigation are altering the composition of the overflow decisively. A computerised model system developed for Hungarian conditions facilitates the prognoses, which opens the possibility of reutilisation of solutions even in more exigent production, e.g. in soil.

As far as the conditions of nutrients cannot be regulated, less sensitive cultures may be fed by the overflow of hydricultures (fertilisation of ornamentals for public domain, lawns, etc.). The nutrient content of the overflow cannot be ignored, therefore it should not be drained into surface waters, consequently, it should be distributed into soils.

The majority of Hungarian farms have an open production system, which means that the nutrients involved ought to be utilised optimally. The analysis of the waters examined during the experiments called our attention on the deleterious effect of waters being of unfavourable composition. In hydroculture, water quality is impaired mainly by salinity, moreover by high sodium content. But the low concentration is more decisive than the rate within the salt. While some authors suggest that $SAR<2$, our results prefer $SAR<1$ being better.

Beside water quality, there are further technological possibilities, which may improve the utilisation of nutrients. As a proof, the variable degrees of nutrient utilisation of the production experiments are mentioned. One of the key conditions, optimisation of the watering procedure has to be mentioned, being decisive in regulating the volume and concentration of the overflow.

In order to keep ideal conditions around the roots for a maximum of nutrient utilisation, the composition of the nutritive solution ought to be changed by adapting it to Hungarian conditions.

4.4. The closed system of production

Under Hungarian conditions, closed soil less production systems are rarely found. According to the present environmental prescriptions, closed systems are expected to release nutrients under unfavourable conditions only. The solution of the question involves the right choice of the medium of the soil less culture. The closed system is preferred not only by environmental arguments but also by economical reasons because the experimental results proved a 20-70% loss of the nutrients, which left the system in the overflow.

The key risk of closed production systems is the necessity of disinfecting. Procedures with well fitting elements as well as chemically neutral means are needed. As best methods, the use of ozone and UV irradiation is considered.

An optimisation of nutrient utilisation may help by electronic means with sounds sensing ions selectively (mainly for nitrogen and potassium); those methods are not applied yet, but are theoretically developed already.

The second critical point of closed production systems is the accumulation of salt. Its main source is the salt content of the respective water resource utilised. If the principle will be accepted that layer waters should not be used for irrigation in the future, the use of surface waters and ground waters will represent the only open possibilities. As surface waters cause additional concerns, the use of ground waters present the highest feasibility but only after being desalted entirely. Desalted water is fitting well into the closed system with the charge of increased investments.

The particular procedures of the technologies should be revised according to being applied either to an open or to a closed system. For that purpose, the former questions are to be answered and objectives of development are to be set in the near future.

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